EFFECTS OF THE ION CHARGE STATES IN LUNAR ILMENITES; G.K.Ustinova, Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow 117991 Russia

The noble gases in the lunar ilmenites [1,2] are analyzed with respect to the charge states of their ions in the solar wind and with respect to the shock wave acceleration of the solar energetic particles.

Introduction: The solar wind (SW) and the solar energetic particles (SEP, 1-50 MeV/*n*), being two distinguishable components of the solar corpuscular emanation, provide the direct clue to the processes in the corona and the chromosphere [3,4]. Indeed, the chromosphere and the lowest layers of the corona are the likely regions of the atom-ion separation, depending on the first ionization potential (FIP) of the elements; the charge states of the ions are eventually formed in equilibrium with the local electron temperature $T_e(r)$ and density $n_e(r)$ and they remain unaltered in further processes. Thus, the physical conditions above the photosphere can be studied by deriving the charge states of SW and SEP. Both the components are distinguished by their isotopic and elemental abundances. SEP, associated with the solar flares, are considered to be shock wave accelerated before injection from the corona and/or during propagation in the heliosphere. This leads to the SEP fractionation in proportion to A/Z or $(A/Z)^2$ (to A/Q or $(A/Q)^2$, where Q is the ion charge (see Table 1), if the ionization is incomplete) [5]. In the case of i and j isotopes of the same element the fractionation is proportional to A^i/A^j or $(A^i/A^j)^2$, i.e. to the common mass-fractionation.

Lunar ilmenites: The SEP fractionation is strongly variable from event to event, so that its long-time average values provided with implanted noble gases in meteorites and lunar samples are of paramount importance. The CSSE* data [1,2] in the lunar ilmenites: soil 71501 (I71) with exposure age ~100 Ma and breccia 79035 (I79) with that of ~1 Ga, are especially valuable. The solar noble gases, released by CSSE from the initial $I71_{(1)}$ and $I79_{(3\text{-}4)}$ steps of etching, turned out to be unfractionated SW noble gases, and those from the deep $I71_{(13)}$ and $I79_{(16\text{-}17)}$ steps were noticeably heavier, like the SEP noble gases (see rows 3, 7 and 6,10 in Table 2). The effects of higher diffusion losses of lighter gases were recorded in element ratios during the first etching steps. Indeed, our corrections of the ratios, in accordance with the self-diffusion coefficients from Table 1, equalize the SW_{I71} and SW_{I79} compositions with those in the SW [6] and in the solar system [7] (see yellow and green cells of Table 2). Taking into account the mass-fractionation only, the authors of [1,2] get the "paradox" that ratios of light gases ($^4He/^{36}Ar$ and $^{20}Ne/^{36}Ar$) grow with the depth, whereas the $^{84}Kr/^{132}Xe$ ratio remains essentially constant. Let us notice that A/Z=2 for both the isotopes of each pair of the light noble gases, so that their relative abundances have not to be changed during SEP acceleration, but have to remain the same as in SW (if ionization was complete). With heavy gases, A/Z=2.33 for ^{84}Kr and A/Z=2.44 for ^{132}Xe, so that their relative abundances have to vary during SEP acceleration (their ratio should decrease with the depth, but it is masked by the higher losses of lighter Kr near the surface). It is more likely, however, that ionization in the chromosphere is not complete [4]. Our modelling leads to the average charge states for ~100 Ma (Q_{I71}) and for ~1 Ga (Q_{I79}) listed in Table 1.

Table 1 Self-diffusion coefficients D_0 [8] of the noble gases and the charge states Q of their ions: Q_{SW} - in the modern SW [4]; Q_{I71} and Q_{I79} - in the SW, averaged for ~100 Ma and ~1 Ga, respectively [this work]

Parameter	Ne	Ar	Kr	Xe
D_0, cm^2/s	0.452	0.156	0.08	0.048
Z	10	18	36	54
Q_{SW} (200-400 eV)**	8	9	12	14
Q_{I71} (700-800 eV)**	8	14	18-19	18
Q_{I79} (900-1000 eV)**	8	16	21-23	23

* CSSE - closed system stepped etching; ** - a range of the ionization potential P_I is indicated in the parentheses.

Indeed, using these charges and SEP fractionation in shock waves in proportion to $(A/Q)^2$ (see parameters K_{I71} and K_{I79}), one can convert the diffusion-corrected $SW_{I71(1)}$ and $SW_{I79(3\text{-}4)}$ data for the initial etching steps to the corresponding SEP relations, which fit closely the measured ratios of isotopes and elements in the deep $I71_{(13)}$ and $I79_{(16\text{-}17)}$ fractions (see blue and rose rows, respectively, in Table 2). Notice that the same approach have been used to the isotopic as well as to the elemental ratios. The best fit for Kr (marked by *) is observed under the different charge states of its isotopes, namely, 18-19 in the similar proportion for ^{82}Kr and 19 for ^{84}Kr in I71, and 21-22 in the similar proportion for ^{82}Kr and 23 for ^{84}Kr in I79. The obtained charge states in Table 1 are rather higher than those for the modern SW [4], the average charge states for ~1 Ga being rather higher than those for ~100 Ma, but, on the whole, they all lie in the temperature range of $2\text{-}4 \cdot 10^6$ K, in which the solar activity variation may be expected over that time scale .

References: [1] Benkert J.-P. et al.(1993) *JGR, 98,* 13147-13162. [2] Wieler R., and Baur H. (1994) *Meteoritics, 29,* 570-580. [3] Meyer J.-P. (1985) *Ap. J. Suppl. 57,* 151-294. [4] Geiss J. (1985) *Proc. ESA Worksh. Fut. Miss. Sol. Heliosph. Sp. Plasm. Phys.,* ESA SP-235, 37-50. [5] Eichler D. and Hainebach K. (1981) *Phys. Rev. Lett., 47,* 1560-1563. [6] Geiss J. and Bochsler P. (1985) *Rapports isotopiques dans le systeme solaire.* Paris: CNES. 213-220. [7] Anders E. and Grevesse N. (1989) *GCA, 53,* 197-214. [8] *Phys. Values: Handbook* (1991) M: Energoatomizdat. P.375.

Table 2 Modelling the noble gas ratios of the SW and SEP components in the lunar ilmenites I71 and I79 (here are $K_{I71} = (A^i/Q^i_{I71})^2 / (A^j/Q^j_{I71})^2$ and $K_{I79} = (A^i/Q^i_{I79})^2 / (A^j/Q^j_{I79})^2$)

Composition	$^{20}Ne/^{22}Ne$	$^{36}Ar/^{38}Ar$	$^{20}Ne/^{36}Ar$	$^{36}Ar/^{84}Kr$	$^{82}Kr/^{84}Kr$	$^{130}Xe/^{132}Xe$	$^{84}Kr/^{132}Xe$
Sol. Syst. [7]	13.68	5.31	37.65	3307	0.2004	0.1653	20.73
SW [6]	13.7±0.3	5.3±0.3	42.5		0.2005	0.1643	
SW - I71 $_{(1)}$ [1,2]	13.81	5.46	13.91	2043	0.2037	0.1659	12.46
$SW_{I71}=I71_{(1)}\cdot\frac{D_0^i}{D_0^j}$	13.81	5.46	40.3	3984	0.2037	0.1659	20.77
SEP - $SW_{I71}\cdot K_{I71}$	11.41	4.90	38.09	1348	0.2052*	0.1609	7.55
SEP - I71 $_{(13)}$ [1,2]	11.21	4.68	38.64	1308	0.2079	0.1586	7.97
SW - I79 $_{(3\text{-}4)}$ [1,2]	13.47	5.43	10.67	2160	0.2119	0.1761	4.64
$SW_{I79}=I79_{(3\text{-}4)}\cdot\frac{D_0^i}{D_0^j}$	13.47	5.43	30.91	4212	0.2119	0.1761	7.74
SEP - $SW_{I79}\cdot K_{I79}$	11.13	4.87	38.16	1598	0.2315*	0.1708	3.13
SEP -I79$_{(16\text{-}17)}$ [1,2]	11.12	4.72	37.51	1547	0.2306	0.1635	3.53